MCS6500 MICROPROCESSORS

The MCS6500 Microprocessor Family Concept -----

The MCS6500 Series Microprocessors represent the first totally software compatible microprocessor family. This family of products includes a range of software compatible microprocessors which provide a selection of addressable memory range, interrupt input options and on-chip clock osscillators and drivers. All of the microprocessors in the MCS6500 group are software compatible within the group and are bus compatible with the M6800 product offering.

The family includes five microprocessors with on-board clock oscillators and drivers and four microprocessors driven by external clocks. The on-chip clock versions are aimed at high performance, low cost applications where single phase inputs, crystal or RC inputs provide the time base. The external clock versions are geared for the multi processor system applications where maximum timing control is mandatory. All versions of the microprocessors are available in 1 MHz and 2 MHz ("A" suffix on product numbers) maximum operating frequencies.

Features of the MCS6500 Family

- Single five volt supply
- N channel, silicon gate, de-pletion load technology
- Eight bit parallel processing
- 56 Instructions
- Decimal and binary arithmetic
- Thirteen addressing modes
- True indexing capability
- Programmable stack pointer
- Variable length stack
- Interrupt capability
- Non-maskable interrupt
- Use with any type or speed memory
- Bi-directional Data Bus

- Instruction decoding and control
- Addressable memory range of up to 65K bytes
- "Ready" input
- Direct memory access capability
- Bus compatible with MC6800
- Choice of external or on-board clocks
- 1MHz and 2MHz operation
- On-the-chip clock options
  * External single clock input
  * RC time base input
  * Crystal time base input
- 40 and 28 pin package versions
- Pipeline architecture

Members of the Family

Microprocessors with
On-Board Clock Oscillator

— MCS6502
— MCS6503
— MCS6504
— MCS6505
— MCS6506

Microprocessors with
External Two Phase
Clock Input

— MCS6512
— MCS6513
— MCS6514
— MCS6515

Comments on the Data Sheet

The data sheet is constructed to review first the basic "Common Characteristics" - those features which are common to the general family of microprocessors. Subsequent to a review of the family characteristics will be sections devoted to each member of the group with specific features of each.

COMMON CHARACTERISTICS

← REGISTER SECTION   CONTROL SECTION →

RES IRQ NMI

INTERRUPT LOGIC

INDEX REGISTER Y

INDEX REGISTER X

STACK POINT REGISTER (S)

ALU

INSTRUCTION DECODE

RDY

ACCUMULATOR A

TIMING CONTROL

PCL

PCH

ϕ_1
ϕ_2

ϕ_1 (IN)
ϕ_2 (IN)

MCS6512,13,14,15

PROCESSOR STATUS REGISTER P

CLOCK GENERATOR

CLOCK INPUT

MCS6502,3,4,5,6

INPUT DATA LATCH (DL)

ϕ_1 OUT
ϕ_2 OUT
R/W
DBE

DATA BUS BUFFER

INSTRUCTION REGISTER

ABL

ABH

INTERNAL ADL

INTERNAL ADH

ADDRESS BUS

AB0
AB1
AB2
AB3
AB4
AB5
AB6
AB7
AB8
AB9
AB10
AB11
AB12
AB13
AB14
AB15

DB0
DB1
DB2
DB3
DB4
DB5
DB6
DB7

DATA BUS

LEGEND:

⇑ = 8 BIT LINE

| = 1 BIT LINE

Note: 1. Clock Generator is not included on MCS6512,13,14,15

2. Addressing Capability and control options vary with each of the MCS6500 Products.

MCS6500 Internal Architecture

MAXIMUM RATINGS

RATING	SYMBOL	VALUE	UNIT
SUPPLY VOLTAGE	V_{cc}	−0.3 to +7.0	Vdc
INPUT VOLTAGE	V_{in}	−0.3 to +7.0	Vdc
OPERATING TEMPERATURE	T_A	0 to +70	°C
STORAGE TEMPERATURE	T_{STG}	−55 to +150	°C

This device contains input protection against damage due to high static voltages or electric fields; however, precautions should be taken to avoid application of voltages higher than the maximum rating.

ELECTRICAL CHARACTERISTICS (V_{cc} = 5.0V ± 5%, V_{ss} = 0, T_A = 25° C)

$\emptyset_1$, $\emptyset_2$ applies to MCS6512, 13, 14, 15, $\emptyset_o$ (in) applies to MCS6502, 03, 04, 05 and 06

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNIT
Input High Voltage	V_{IH}				Vdc
Logic, $\emptyset_o$(in)		Vss + 2.4	–	Vcc	
$\emptyset_1$, $\emptyset_2$		Vcc − 0.2	–	Vcc + 0.25	
Input Low Voltage	V_{IL}				Vdc
Logic, $\emptyset_o$(in)		Vss − 0.3	–	Vss + 0.4	
$\emptyset_1$, $\emptyset_2$		Vss − 0.3	–	Vss + 0.2	
Input High Threshold Voltage	V_{IHT}				
$\overline{RES}$, $\overline{NMI}$, RDY, $\overline{IRQ}$, Data, S.O.		Vss + 2.0	–	–	Vdc
Input Low Threshold Voltage	V_{ILT}				
$\overline{RES}$, $\overline{NMI}$, RDY, $\overline{IRQ}$, Data, S.O.		–	–	Vss + 0.8	Vdc
Input Leakage Current	I_{in}				
(V_{in} = 0 to 5.25V, V_{cc} = 0)					
Logic (Excl.RDY, S.O.)		–	–	2.5	µA
$\emptyset_1$, $\emptyset_2$		–	–	100	µA
$\emptyset_o$(in)		–	–	10.0	µA
Three-State (Off State) Input Current	I_{TSI}				µA
(V_{in} = 0.4 to 2.4V, V_{cc} = 5.25V)					
Data Lines		–	–	10	
Output High Voltage	V_{OH}				
(I_{LOAD} = −100µAdc, V_{cc} = 4.75V)					
SYNC, Data, A0–A15, R/W		Vss + 2.4	–	–	Vdc
Output Low Voltage	V_{OL}				
(I_{LOAD} = 1.6mAdc, V_{cc} = 4.75V)					
SYNC, Data, A0–A15, R/W		–	–	Vss + 0.4	Vdc
Power Dissipation	P_D	–	.25	.70	W
Capacitance	C				pF
(V_{in} = 0, T_A = 25°C, f = 1MHz)					
Logic	C_{in}	–	–	10	
Data		–	–	15	
A0–A15, R/W, SYNC	C_{out}	–	–	12	
$\emptyset_o$(in)	$C_{\emptyset_o(in)}$	–	–	15	
$\emptyset_1$	$C_{\emptyset_1}$	–	30	50	
$\emptyset_2$	$C_{\emptyset_2}$	–	50	80	

Note: $\overline{IRQ}$ and $\overline{NMI}$ require 3K pull-up resistors.

Note: "REF." means Reference Points on clocks.

Clock Timing — MCS6502, 03, 04, 05, 06

ØO (IN)
ØI (OUT)
Ø2 (OUT)

REF "A"
REF "B"

0.4V 1.5V TFØO PWHØOL PWHØOH 1.5V TRØO 2.4V .4V
.4V 1.5V PWHØI 1.5V
1.5V .4V PWHØ2 1.5V

Clock Timing — MCS6512, 13, 14, 15

Ø1
Ø2

REF "A"
REF "B"

0.2V TF VCC-0.2V TD 0.2V PWHØI VCC-0.2V TCYC TR PWHØ2
TD
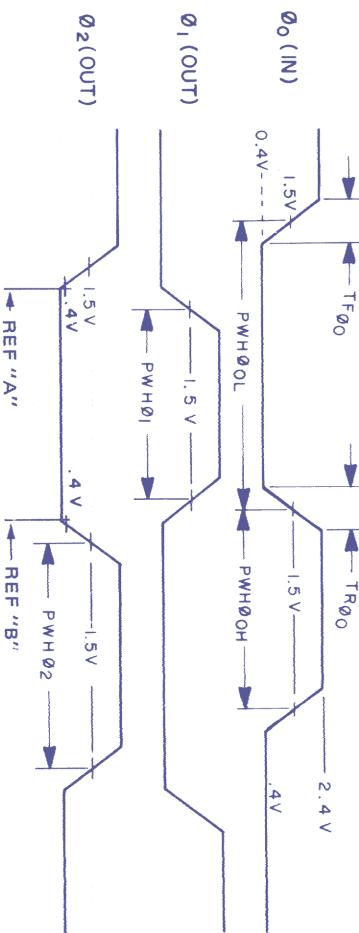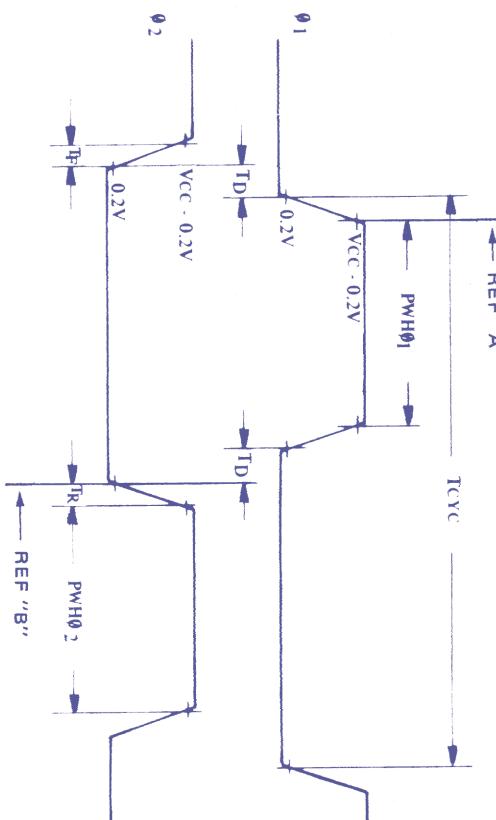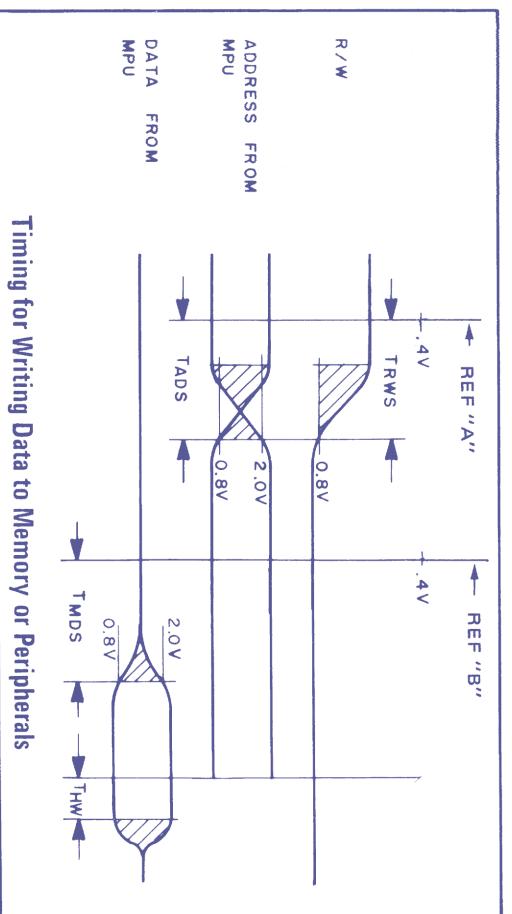
Timing for Reading Data from Memory or Peripherals

R/W
ADDRESS FROM MPU
DATA FROM MEMORY
RDY, S.O
SYNC

REF "A"
REF "B"

.4V TRWS 2.0V 0.8V 2.0V THRW
TADS 0.8V 2.0V THA
TSYNC TRDY,SO TACC 0.8V 2.0V TDSU .4V
TRW 0.8V 2.0V 2.0V THR
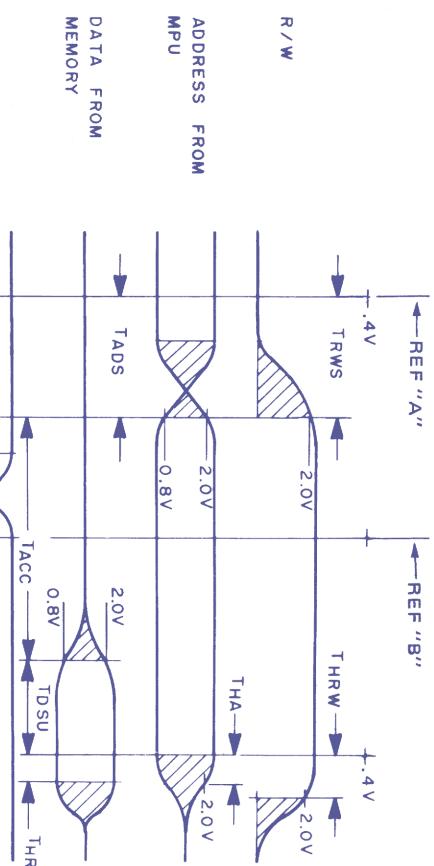
Timing for Writing Data to Memory or Peripherals

R/W
ADDRESS FROM MPU
DATA FROM MPU

REF "A"
REF "B"

.4V TRWS 0.8V 2.0V
TADS 0.8V
.4V TMDS 2.0V 0.8V THW

1 MHz TIMING

Clock Timing — MCS6512, 13, 14, 15

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNIT
Cycle Time	T_{CYC}	1000	---	---	nsec
Clock Pulse Width (Measured at Vcc - 0.2v) Ø1 Ø2	PWH Ø1 PWH Ø2	430 470	---	---	nsec
Fall Time (Measured from 0.2v to Vcc - 0.2v)	T_F	---	---	25	nsec
Delay Time between Clocks (Measured at 0.2v)	T_D	0	---	---	nsec

CLOCK TIMING -MCS6502, 03, 04, 05, 06

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNITS
Cycle Time	T_{CYC}	1000	--	--	ns
ϕ_o(IN) Pulse Width (measured at 1.5V)	$PWH\phi_o$	460	--	520	ns
ϕ_o(IN) Rise, Fall Time	$TR\phi_o, TF\phi_o$	--	--	10	ns
Delay Time Between Clocks (measured at 1.5V)	T_D	5	--	--	ns
ϕ_1(OUT) Pulse Width (measured at 1.5V)	$PWH\phi_1$	$PWH\phi_{oL}-20$	--	$PWH\phi_{oL}$	ns
ϕ_2(OUT) Pulse Width (measured at 1.5V)	$PWH\phi_2$	$PWH\phi_{oH}-40$	--	$PWH\phi_{oH}-10$	ns
ϕ_1(OUT), ϕ_2(OUT) Rise, Fall Time (Load = 30pf (measured .8V to 2.0 V) + 1 TTL)	T_R, T_F	--	--	25	ns

READ/WRITE TIMING

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNITS
Read/Write Setup Time from MCS6500	T_{RWS}	--	100	300	ns
Address Setup Time from MCS6500	T_{ADS}	--	100	300	ns
Memory Read Access Time	T_{ACC}	--	--	575	ns
Data Stability Time Period	T_{DSU}	100	--	--	ns
Data Hold Time - Read	T_{HR}	10	--	--	ns
Data Hold Time - Write	T_{HW}	30	60	--	ns
Data Setup Time from MCS6500	T_{MDS}	--	150	200	ns
RDY, S.O. Setup Time	T_{RDY}	100	--	--	ns
SYNC Setup Time from MCS6500	T_{SYNC}	--	--	350	ns
Address Hold Time	T_{HA}	30	60	--	ns
R/W Hold Time	T_{HRW}	30	60	--	ns

2 MHz TIMING

Clock Timing — MCS6512, 13, 14, 15, 16

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNIT
Cycle Time	T_{CYC}	500	---	---	nsec
Clock Pulse Width (Measured at Vcc - 0.2v) Ø1 Ø2	PWH Ø1 PWH Ø2	215 235	---	---	nsec
Fall Time (Measured from 0.2v to Vcc - 0.2v)	T_F	---	---	12	nsec
Delay Time between Clocks (Measured at 0.2v)	T_D	0	---	---	nsec

CLOCK TIMING - MCS6502, 03, 04, 05, 06

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNITS
Cycle Time	T_{CYC}	500	--	--	ns
ϕ_o(IN) Pulse Width (measured at 1.5V)	$PWH\phi_o$	240	--	260	ns
ϕ_o(IN) Rise, Fall Time	$TR\phi_o, TF\phi_o$	--	--	10	ns
Delay Time Between Clocks (measured at 1.5V)	T_D	5	--	--	ns
ϕ_1(OUT) Pulse Width (measured at 1.5V)	$PWH\phi_1$	$PWH\phi_{oL}-20$	--	$PWH\phi_{oL}$	ns
ϕ_2(OUT) Pulse Width (measured at 1.5V)	$PWH\phi_2$	$PWH\phi_{oH}-40$	--	$PWH\phi_{oH}-10$	ns
ϕ_1(OUT), ϕ_2(OUT) Rise, Fall Time (Load = 30pf (measured .8V to 2.0 V) + 1 TTL)	T_R, T_F	--	--	25	ns

READ/WRITE TIMING

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNITS
Read/Write Setup Time from MCS6500A	T_{RWS}	--	100	150	ns
Address Setup Time from MCS6500A	T_{ADS}	--	100	150	ns
Memory Read Access Time	T_{ACC}	--	--	300	ns
Data Stability Time Period	T_{DSU}	50	--	--	ns
Data Hold Time - Read	T_{HR}	10	--	--	ns
Data Hold Time - Write	T_{HW}	30	60	--	ns
Data Setup Time from MCS6500A	T_{MDS}	--	75	100	ns
RDY, S.O. Setup Time	T_{RDY}	50	--	--	ns
SYNC Setup Time from MCS6500A	T_{SYNC}	--	--	175	ns
Address Hold Time	T_{HA}	30	60	--	ns
R/W Hold Time	T_{HRW}	30	60	--	ns

Clocks ($\emptyset_1$, $\emptyset_2$)

    The MCS651X requires a two phase non-overlapping clock that runs at the Vcc voltage level.

    The MCS650X clocks are supplied with an internal clock generator. The frequency of these clocks is externally controlled. Details of this feature are discussed in the MCS6502 portion of this data sheet.

Address Bus (A_0-A_{15}) (See sections on each micro for respective address lines on those devices.)

    These outputs are TTL compatible, capable of driving one standard TTL load and 130pf.

Data Bus (D_0-D_7)

    Eight pins are used for the data bus. This is a bi-directional bus, transferring data to and from the device and peripherals. The outputs are tri-state buffers capable of driving one standard TTL load and 130pf.

Data Bus Enable (DBE)

    This TTL compatible input allows external control of the tri-state data output buffers and will enable the microprocessor bus driver when in the high state. In normal operation DBE would be driven by the phase two ($\emptyset_2$) clock, thus allowing data output from microprocessor only during $\emptyset_2$. During the read cycle, the data bus drivers are internally disabled, becoming essentially an open circuit. To disable data bus drivers externally, DBE should be held low.

Ready (RDY)

    This input signal allows the user to single cycle the microprocessor on all cycles except write cycles. A negative transition to the low state during or coincident with phase one ($\emptyset_1$) will halt the microprocessor with the output address lines reflecting the current address being fetched. This condition will remain through a subsequent phase two ($\emptyset_2$) in which the Ready signal is low. This feature allows microprocessor interfacing with low speed PROMS as well as fast (max. 2 cycle) Direct Memory Access (DMA). If Ready is low during a write cycle, it is ignored until the following read operation.

Interrupt Request ($\overline{\text{IRQ}}$)

    This TTL level input requests that an interrupt sequence begin within the microprocessor. The microprocessor will complete the current instruction being executed before recognizing the request. At that time, the interrupt mask bit in the Status Code Register will be examined. If the interrupt mask flag is not set, the microprocessor will begin an interrupt sequence. The Program Counter and Processor Status Register are stored in the stack. The microprocessor will then set the interrupt mask flag high so that no further interrupts may occur. At the end of this cycle, the program counter low will be loaded from address FFFE, and program counter high from location FFFF, therefore transferring program control to the memory vector located at these addresses. The RDY signal must be in the high state for any interrupt to be recognized. A 3KΩ external resistor should be used for proper wire-OR operation.

Non-Maskable Interrupt ($\overline{\text{NMI}}$)

    A negative going edge on this input requests that a non-maskable interrupt sequence be generated within the microprocessor.

    $\overline{\text{NMI}}$ is an unconditional interrupt. Following completion of the current instruction, the sequence of operations defined for $\overline{\text{IRQ}}$ will be performed, regardless of the state interrupt mask flag. The vector address loaded into the program counter, low and high, are locations FFFA and FFFB respectively, thereby transferring program control to the memory vector located at these addresses. The instructions loaded at these locations cause the microprocessor to branch to a non-maskable interrupt routine in memory.

    $\overline{\text{NMI}}$ also requires an external 3KΩ register to Vcc for proper wire-OR operations.

    Inputs $\overline{\text{IRQ}}$ and $\overline{\text{NMI}}$ are hardware interrupts lines that are sampled during $\emptyset_2$ (phase 2) and will begin the appropriate interrupt routine on the $\emptyset_1$ (phase 1) following the completion of the current instruction.

Set Overflow Flag (S.O.)

    A NEGATIVE going edge on this input sets the overflow bit in the Status Code Register. This signal is sampled on the trailing edge of $\emptyset_1$.

SYNC

    This output line is provided to identify those cycles in which the microprocessor is doing an OP CODE fetch. The SYNC line goes high during $\emptyset_1$ of an OP CODE fetch and stays high for the remainder of that cycle. If the RDY line is pulled low during the $\emptyset_1$ clock pulse in which SYNC went high, the processor will stop in its current state and will remain in the state until the RDY line goes high. In this manner, the SYNC signal can be used to control RDY to cause single instruction execution.

Reset

    This input is used to reset or start the microprocessor from a power down condition. During the time that this line is held low, writing to or from the microprocessor is inhibited. When a positive edge is detected on the input, the microprocessor will immediately begin the reset sequence.

    After a system initialization time of six clock cycles, the mask interrupt flag will be set and the microprocessor will load the program counter from the memory vector locations FFFC and FFFD. This is the start location for program control.

    After Vcc reaches 4.75 volts in a power up routine, reset must be held low for at least two clock cycles. At this time the R/W and (SYNC) signal will become valid.

    When the reset signal goes high following these two clock cycles, the microprocessor will proceed with the normal reset procedure detailed above.

INSTRUCTION SET – ALPHABETIC SEQUENCE

ADC	Add Memory to Accumulator with Carry	
AND	"AND" Memory with Accumulator	
ASL	Shift left One Bit (Memory or Accumulator)	
BCC	Branch on Carry Clear	
BCS	Branch on Carry Set	
BEQ	Branch on Result Zero	
BIT	Test Bits in Memory with Accumulator	
BMI	Branch on Result Minus	
BNE	Branch on Result not Zero	
BPL	Branch on Result Plus	
BRK	Force Break	
BVC	Branch on Overflow Clear	
BVS	Branch on Overflow Set	

ADC Add Memory to Accumulator with Carry
AND "AND" Memory with Accumulator
ASL Shift left One Bit (Memory or Accumulator)

BCC Branch on Carry Clear
BCS Branch on Carry Set
BEQ Branch on Result Zero
BIT Test Bits in Memory with Accumulator
BMI Branch on Result Minus
BNE Branch on Result not Zero
BPL Branch on Result Plus
BRK Force Break
BVC Branch on Overflow Clear
BVS Branch on Overflow Set

CLC Clear Carry Flag
CLD Clear Decimal Mode
CLI Clear Interrupt Disable Bit
CLV Clear Overflow Flag
CMP Compare Memory and Accumulator
CPX Compare Memory and Index X
CPY Compare Memory and Index Y

DEC Decrement Memory by One
DEX Decrement Index X by One
DEY Decrement Index Y by One

EOR "Exclusive-or" Memory with Accumulator

INC Increment Memory by One
INX Increment Index X by One
INY Increment Index Y by One

JMP Jump to New Location
JSR Jump to New Location Saving Return Address

LDA Load Accumulator with Memory
LDX Load Index X with Memory
LDY Load Index Y with Memory
LSR Shift One Bit Right (Memory or Accumulator)

NOP No Operation

ORA "OR" Memory with Accumulator

PHA Push Accumulator on Stack
PHP Push Processor Status on Stack
PLA Pull Accumulator from Stack
PLP Pull Processor Status from Stack

ROL Rotate One Bit Left (Memory or Accumulator)
ROR Rotate One Bit Right (Memory or Accumulator)
RTI Return from Interrupt
RTS Return from Subroutine

SBC Subtract Memory from Accumulator with Borrow
SEC Set Carry Flag
SED Set Decimal Mode
SEI Set Interrupt Disable Status
STA Store Accumulator in Memory
STX Store Index X in Memory
STY Store Index Y in Memory

TAX Transfer Accumulator to Index X
TAY Transfer Accumulator to Index Y
TSX Transfer Stack Pointer to Index X
TXA Transfer Index X to Accumulator
TXS Transfer Index X to Stack Pointer
TYA Transfer Index Y to Accumulator

ADDRESSING MODES

ACCUMULATOR ADDRESSING – This form of addressing is represented with a one byte instruction, implying an operation on the accumulator.

IMMEDIATE ADDRESSING – In immediate addressing, the operand is contained in the second byte of the instruction, with no further memory addressing required.

ABSOLUTE ADDRESSING – In absolute addressing, the second byte of the instruction specifies the eight low order bits of the effective address while the third byte specifies the eight high order bits. Thus, the absolute addressing mode allows access to the entire 65K bytes of addressable memory.

ZERO PAGE ADDRESSING – The zero page instructions allow for shorter code and execution times by only fetching the second byte of the instruction and assuming a zero high address byte. Careful use of the zero page can result in significant increase in code efficiency.

INDEXED ZERO PAGE ADDRESSING – (X, Y indexing) – This form of addressing is used in conjunction with the index register and is referred to as "Zero Page, X" or "Zero Page, Y". The effective address is calculated by adding the second byte to the contents of the index register. Since this is a form of "Zero Page" addressing, the content of the second byte references a location in page zero. Additionally due to the "Zero Page" addressing nature of this mode, no carry is added to the high order 8 bits of memory and crossing of page boundaries does not occur.

INDEXED ABSOLUTE ADDRESSING – (X, Y indexing) – This form of addressing is used in conjunction with X and Y index register and is referred to as "Absolute, X", and "Absolute, Y". The effective address is formed by adding the contents of X or Y to the address contained in the second and third bytes of the instruction. This mode allows the index register to contain the index or count value and the instruction to contain the base address. This type of indexing allows any location referencing and the index to modify multiple fields resulting in reduced coding and execution time.

IMPLIED ADDRESSING – In the implied addressing mode, the address containing the operand is implicitly stated in the operation code of the instruction.

RELATIVE ADDRESSING – Relative addressing is used only with branch instructions and establishes a destination for the conditional branch.

The second byte of the instruction becomes the operand which is an "Offset" added to the contents of the lower eight bits of the program counter when the counter is set at the next instruction. The range of the offset is –128 to +127 bytes from the next instruction.

INDEXED INDIRECT ADDRESSING – In indexed indirect addressing (referred to as (Indirect,X)), the second byte of the instruction is added to the contents of the X index register, discarding the carry. The result of this addition points to a memory location on page zero whose contents is the low order eight bits of the effective address. The next memory location in page zero contains the high order eight bits of the effective address. Both memory locations specifying the high and low order bytes of the effective address must be in page zero.

INDIRECT INDEXED ADDRESSING – In indirect indexed addressing (referred to as (Indirect),Y), the second byte of the instruction points to a memory location in page zero. The contents of this memory location is added to the contents of the Y index register, the result being the low order eight bits of the effective address. The carry from this addition is added to the contents of the next page zero memory location, the result being the high order eight bits of the effective address.

ABSOLUTE INDIRECT – The second byte of the instruction contains the low order eight bits of a memory location. The high order eight bits of that memory location is contained in the third byte of the instruction. The contents of the fully specified memory location is the low order byte of the effective address. The next memory location contains the high order byte of the effective address which is loaded into the sixteen bits of the program counter.
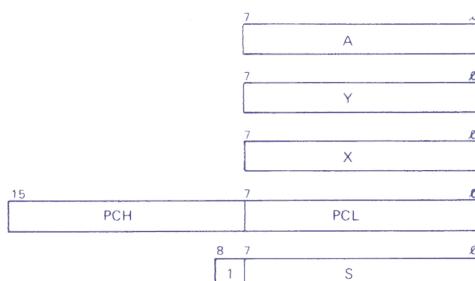
PROGRAMMING MODEL

7		0			
	A		ACCUMULATOR	A	

7		0			
	Y		INDEX REGISTER	Y	

7		0			
	X		INDEX REGISTER	X	

15		7		0		
PCH			PCL		PROGRAM COUNTER	"PC"

8	7		0		
1		S		STACK POINTER	"S"

Processor Status Reg "P":

7							0
N	V		B	D	I	Z	C

PROCESSOR STATUS REG "P"

- CARRY   1 = TRUE
- ZERO   1 = RESULT ZERO
- IRQ DISABLE   1 = DISABLE
- DECIMAL MODE   1 = TRUE
- BRK COMMAND
- OVERFLOW   1 = TRUE
- NEGATIVE   1 = NEG.
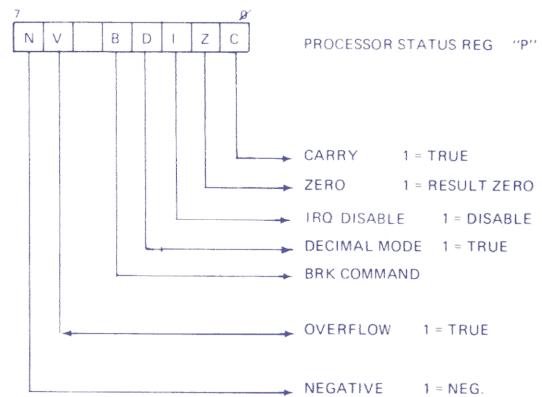
INSTRUCTION SET — OP CODES, Execution Time, Memory Requirements

MNEMONIC	OPERATION	IMMEDIATE OP N #	ABSOLUTE OP N #	ZERO PAGE OP N #	ACCUM. OP N #	IMPLIED OP N #	(IND,X) OP N #	(IND),Y OP N #	Z,PAGE,X OP N #	ABS,X OP N #	ABS,Y OP N #	RELATIVE OP N #	INDIRECT OP N #	Z,PAGE,Y OP N #	CONDITION CODES N Z C I D V
A D C	A+M+C → A (4)(1)	69 2 2	6D 4 3	65 3 2			61 6 2	71 5 2	75 4 2	7D 4 3	79 4 3				√ √ √ – – √
A N D	A∧M→A (1)	29 2 2	2D 4 3	25 3 2			21 6 2	31 5 2	35 4 2	3D 4 3	39 4 3				√ √ – – – –
A S L	C←□←0		0E 6 3	06 5 2	0A 2 1				16 6 2	1E 7 3					√ √ √ – – –
B C C	BRANCH ON C=0 (2)											90 2 2			– – – – – –
B C S	BRANCH ON C=1 (2)											B0 2 2			– – – – – –
B E Q	BRANCH ON Z=1 (2)											F0 2 2			– – – – – –
B I T	A∧M		2C 4 3	24 3 2											M₇ √ – – – M₆
B M I	BRANCH ON N=1 (2)											30 2 2			– – – – – –
B N E	BRANCH ON Z=0 (2)											D0 2 2			– – – – – –
B P L	BRANCH ON N=0 (2)											10 2 2			– – – – – –
B R K	(See Fig. 1)					00 7 1									– – – 1 – –
B V C	BRANCH ON V=0 (2)											50 2 2			– – – – – –
B V S	BRANCH ON V=1 (2)											70 2 2			– – – – – –
C L C	0→C					18 2 1									– – 0 – – –
C L D	0→D					D8 2 1									– – – – 0 –
C L I	0→I					58 2 1									– – – 0 – –
C L V	0→V					B8 2 1									– – – – – 0
C M P	A–M (1)	C9 2 2	CD 4 3	C5 3 2			C1 6 2	D1 5 2	D5 4 2	DD 4 3	D9 4 3				√ √ √ – – –
C P X	X–M	E0 2 2	EC 4 3	E4 3 2											√ √ √ – – –
C P Y	Y–M	C0 2 2	CC 4 3	C4 3 2											√ √ √ – – –
D E C	M–1→M		CE 6 3	C6 5 2					D6 6 2	DE 7 3					√ √ – – – –
D E X	X–1→X					CA									√ √ – – – –
D E Y	Y–1→Y					88									√ √ – – – –
E O R	A∀M→A (1)	49 2 2	4D 4 3	45 3 2			41 6 2	51 5 2	55 4 2	5D 4 3	59 4 3				√ √ – – – –
I N C	M+1→M		EE 6 3	E6 5 2					F6 6 2	FE 7 3					√ √ – – – –
I N X	X+1→X					E8 2 1									√ √ – – – –
I N Y	Y+1→Y					C8 2 1									√ √ – – – –
J M P	JUMP TO NEW LOC.		4C 3 3										6C 5 3		– – – – – –
J S R	(See Fig. 2) JUMP SUB		20 6 3												– – – – – –
L D A	M → A (1)	A9 2 2	AD 4 3	A5 3 2			A1 6 2	B1 5 2	B5 4 2	BD 4 3	B9 4 3				√ √ – – – –

MNEMONIC	OPERATION	IMMEDIATE OP N #	ABSOLUTE OP N #	ZERO PAGE OP N #	ACCUM. OP N #	IMPLIED OP N #	(IND,X) OP N #	(IND),Y OP N #	Z,PAGE,X OP N #	ABS,X OP N #	ABS,Y OP N #	RELATIVE OP N #	INDIRECT OP N #	Z,PAGE,Y OP N #	CONDITION CODES N Z C I D V
L D X	M → X (1)	A2 2 2	AE 4 3	A6 3 2							BE 4 3			B6 4 2	√ √ – – – –
L D Y	M → Y (1)	A0 2 2	AC 4 3	A4 3 2					B4 4 2	BC 4 3					√ √ – – – –
L S R	0→□→C		4E 6 3	46 5 2	4A 2 1				56 6 2	5E 7 3					0 √ √ – – –
N O P	NO OPERATION					EA 2 1									– – – – – –
O R A	A∨M → A (1)	09 2 2	0D 4 3	05 3 2			01 6 2	11 5 2	15 4 2	1D 4 3	19 4 3				√ √ – – – –
P H A	A→Ms S–1→S					48 3 1									– – – – – –
P H P	P→Ms S–1→S					08 3 1									– – – – – –
P L A	S+1→S Ms→A					68 4 1									√ √ – – – –
P L P	S+1→S Ms→P					28 4 1									(RESTORED)
R O L	□←□←C		2E 6 3	26 5 2	2A 2 1				36 6 2	3E 7 3					√ √ √ – – –
R O R	C→□→□		6E 6 3	66 5 2	6A 2 1				76 6 2	7E 7 3					√ √ √ – – –
R T I	(See Fig. 1) RTRN. INT					40 6 1									(RESTORED)
R T S	(See Fig. 2) RTRN SUB					60 6 1									– – – – – –
S B C	A–M–C̄ → A (1)	E9 2 2	ED 4 3	E5 3 2			E1 6 2	F1 5 2	F5 4 2	FD 4 3	F9 4 3				√ √ (3) – – √
S E C	1→C					38 2 1									– – 1 – – –
S E D	1→D					F8 2 1									– – – – 1 –
S E I	1→I					78 2 1									– – – 1 – –
S T A	A→M		8D 4 3	85 3 2			81 6 2	91 6 2	95 4 2	9D 5 3	99 5 3				– – – – – –
S T X	X→M		8E 4 3	86 3 2										96 4 2	– – – – – –
S T Y	Y→M		8C 4 3	84 3 2					94 4 2						– – – – – –
T A X	A → X					AA 2 1									√ √ – – – –
T A Y	A → Y					A8 2 1									√ √ – – – –
T S X	S → X					BA 2 1									√ √ – – – –
T X A	X → A					8A 2 1									√ √ – – – –
T X S	X → S					9A 2 1									– – – – – –
T Y A	Y → A					98 2 1									√ √ – – – –

(1) ADD 1 TO "N" IF PAGE BOUNDARY IS CROSSED.
(2) ADD 1 TO "N" IF BRANCH OCCURS TO SAME PAGE.
    ADD 2 TO "N" IF BRANCH OCCURS TO DIFFERENT PAGE.
(3) CARRY NOT = BORROW.
(4) IF IN DECIMAL MODE Z FLAG IS INVALID.
    ACCUMULATOR MUST BE CHECKED FOR ZERO RESULT.

X   INDEX X
Y   INDEX Y
A   ACCUMULATOR
M   MEMORY PER EFFECTIVE ADDRESS
Ms   MEMORY PER STACK POINTER

∀   EXCLUSIVE OR
+   ADD
–   SUBTRACT
∧   AND
∨   OR

N   NO. CYCLES
NO. BYTES
√   MODIFIED
–   NOT MODIFIED
M₇   MEMORY BIT 7
M₆   MEMORY BIT 6

MCS6502 – 40 Pin Package

```
         Vss —| 1      40 |— RES
         RDY —| 2      39 |— Ø₂(OUT)
     Ø₁(OUT) —| 3      38 |— S.O.
         IRQ —| 4      37 |— Ø₀(IN)
        N.C. —| 5      36 |— N.C.
         NMI —| 6      35 |— N.C.
        SYNC —| 7      34 |— R/W
         Vcc —| 8      33 |— DB0
         AB0 —| 9      32 |— DB1
         AB1 —|10      31 |— DB2
         AB2 —|11      30 |— DB3
         AB3 —|12      29 |— DB4
         AB4 —|13      28 |— DB5
         AB5 —|14      27 |— DB6
         AB6 —|15      26 |— DB7
         AB7 —|16      25 |— AB15
         AB8 —|17      24 |— AB14
         AB9 —|18      23 |— AB13
        AB10 —|19      22 |— AB12
        AB11 —|20      21 |— Vss
```

MCS6502

* 65K Addressable Bytes of Memory
* $\overline{IRQ}$ Interrupt   * $\overline{NMI}$ Interrupt
* On-the-chip Clock
    ✓ TTL Level Single Phase Input
    ✓ RC Time Base Input
    ✓ Crystal Time Base Input
* SYNC Signal
    (can be used for single instruction execution)
* RDY Signal
    (can be used for single cycle execution)
* Two Phase Output Clock for Timing of Support Chips

Features of MCS6502

MCS6503 – 28 Pin Package

```
         RES —| 1      28 |— Ø₂(OUT)
         Vss —| 2      27 |— Ø₀(IN)
         IRQ —| 3      26 |— R/W
         NMI —| 4      25 |— DB0
         Vcc —| 5      24 |— DB1
         AB0 —| 6      23 |— DB2
         AB1 —| 7      22 |— DB3
         AB2 —| 8      21 |— DB4
         AB3 —| 9      20 |— DB5
         AB4 —|10      19 |— DB6
         AB5 —|11      18 |— DB7
         AB6 —|12      17 |— AB11
         AB7 —|13      16 |— AB10
         AB8 —|14      15 |— AB9
```

MCS6503

* 4K Addressable Bytes of Memory (AB00-AB11)

* On-the-chip Clock

* $\overline{IRQ}$ Interrupt

* $\overline{NMI}$ Interrupt

* 8 Bit Bi-Directional Data Bus

Features of MCS6503

MCS6504 – 28 Pin Package

```
         RES —| 1      28 |— Ø₂(OUT)
         Vss —| 2      27 |— Ø₀(IN)
         IRQ —| 3      26 |— R/W
         Vcc —| 4      25 |— DB0
         AB0 —| 5      24 |— DB1
         AB1 —| 6      23 |— DB2
         AB2 —| 7      22 |— DB3
         AB3 —| 8      21 |— DB4
         AB4 —| 9      20 |— DB5
         AB5 —|10      19 |— DB6
         AB6 —|11      18 |— DB7
         AB7 —|12      17 |— AB12
         AB8 —|13      16 |— AB11
         AB9 —|14      15 |— AB10
```

MCS6504

* 8K Addressable Bytes of Memory (AB00-AB12)

* On-the-chip Clock

* $\overline{IRQ}$ Interrupt

* 8 Bit Bi-Directional Data Bus

Features of MCS6504

MCS6505 — 28 Pin Package

```
        ┌──────────┐
 RES  ─┤ 1     28 ├─ Ø₂(OUT)
 Vss  ─┤ 2     27 ├─ Ø₀(IN)
 RDY  ─┤ 3     26 ├─ R/W
 IRQ  ─┤ 4     25 ├─ DB0
 Vcc  ─┤ 5     24 ├─ DB1
 AB0  ─┤ 6     23 ├─ DB2
 AB1  ─┤ 7     22 ├─ DB3
 AB2  ─┤ 8     21 ├─ DB4
 AB3  ─┤ 9     20 ├─ DB5
 AB4  ─┤10     19 ├─ DB6
 AB5  ─┤11     18 ├─ DB7
 AB6  ─┤12     17 ├─ AB11
 AB7  ─┤13     16 ├─ AB10
 AB8  ─┤14     15 ├─ AB9
        └──────────┘
          MCS6505
```

* 4K Addressable Bytes of Memory (AB00-AB11)

* On-the-chip Clock

* $\overline{IRQ}$ Interrupt

* RDY Signal

* 8 Bit Bi-Directional Data Bus

Features of MCS6505

MCS6506 — 28 Pin Package

```
           ┌──────────┐
  RES    ─┤ 1     28 ├─ Ø₂(OUT)
  Vss    ─┤ 2     27 ├─ Ø₀(IN)
Ø₁(OUT)  ─┤ 3     26 ├─ R/W
  IRQ    ─┤ 4     25 ├─ DB0
  Vcc    ─┤ 5     24 ├─ DB1
  AB0    ─┤ 6     23 ├─ DB2
  AB1    ─┤ 7     22 ├─ DB3
  AB2    ─┤ 8     21 ├─ DB4
  AB3    ─┤ 9     20 ├─ DB5
  AB4    ─┤10     19 ├─ DB6
  AB5    ─┤11     18 ├─ DB7
  AB6    ─┤12     17 ├─ AB11
  AB7    ─┤13     16 ├─ AB10
  AB8    ─┤14     15 ├─ AB9
           └──────────┘
            MCS6506
```

* 4K Addressable Bytes of Memory (AB00-AB11)

* On-the-chip Clock

* $\overline{IRQ}$ Interrupt

* Two phases off

* 8 Bit Bi-Directional Data Bus

Features of MCS6506

MCS6512 — 40 Pin Package

```
        ┌──────────┐
 Vss  ─┤ 1     40 ├─ RES
 RDY  ─┤ 2     39 ├─ Ø₂(OUT)
 Ø₁   ─┤ 3     38 ├─ S.O.
 IRQ  ─┤ 4     37 ├─ Ø₂
 Vss  ─┤ 5     36 ├─ DBE
 NMI  ─┤ 6     35 ├─ N.C.
 SYNC ─┤ 7     34 ├─ R/W
 Vcc  ─┤ 8     33 ├─ DB0
 AB0  ─┤ 9     32 ├─ DB1
 AB1  ─┤10     31 ├─ DB2
 AB2  ─┤11     30 ├─ DB3
 AB3  ─┤12     29 ├─ DB4
 AB4  ─┤13     28 ├─ DB5
 AB5  ─┤14     27 ├─ DB6
 AB6  ─┤15     26 ├─ DB7
 AB7  ─┤16     25 ├─ AB15
 AB8  ─┤17     24 ├─ AB14
 AB9  ─┤18     23 ├─ AB13
 AB10 ─┤19     22 ├─ AB12
 AB11 ─┤20     21 ├─ Vss
        └──────────┘
          MCS6512
```

* 65K Addressable Bytes of Memory

* $\overline{IRQ}$ Interrupt

* $\overline{NMI}$ Interrupt

* RDY Signal

* 8 Bit Bi-Directional Data Bus

* SYNC Signal

* Two phase input

* Data Bus Enable

Features of MCS6512

MCS6513 — 28 Pin Package

```
         Vss ─┤ 1      28 ├─ RES
          Ø1 ─┤ 2      27 ├─ Ø2
         IRQ ─┤ 3      26 ├─ R/W
         NMI ─┤ 4      25 ├─ DB0
         Vcc ─┤ 5      24 ├─ DB1
         AB0 ─┤ 6      23 ├─ DB2
         AB1 ─┤ 7      22 ├─ DB3
         AB2 ─┤ 8      21 ├─ DB4
         AB3 ─┤ 9      20 ├─ DB5
         AB4 ─┤ 10     19 ├─ DB6
         AB5 ─┤ 11     18 ├─ DB7
         AB6 ─┤ 12     17 ├─ AB11
         AB7 ─┤ 13     16 ├─ AB10
         AB8 ─┤ 14     15 ├─ AB9
```

MCS6513

Features of MCS6513

* 4K Addressable Bytes of Memory (AB00-AB11)
* Two phase clock input
* $\overline{IRQ}$ Interrupt
* $\overline{NMI}$ Interrupt
* 8 Bit Bi-Directional Data Bus

MCS6514 — 28 Pin Package

```
         Vss ─┤ 1      28 ├─ RES
          Ø1 ─┤ 2      27 ├─ Ø2
         IRQ ─┤ 3      26 ├─ R/W
         Vcc ─┤ 4      25 ├─ DB0
         AB0 ─┤ 5      24 ├─ DB1
         AB1 ─┤ 6      23 ├─ DB2
         AB2 ─┤ 7      22 ├─ DB3
         AB3 ─┤ 8      21 ├─ DB4
         AB4 ─┤ 9      20 ├─ DB5
         AB5 ─┤ 10     19 ├─ DB6
         AB6 ─┤ 11     18 ├─ DB7
         AB7 ─┤ 12     17 ├─ AB12
         AB8 ─┤ 13     16 ├─ AB11
         AB9 ─┤ 14     15 ├─ AB10
```

MCS6514

Features of MCS6514

* 8K Addressable Bytes of Memory (AB00-AB12)
* Two phase clock input
* $\overline{IRQ}$ Interrupt
* 8 Bit Bi-Directional Data Bus

MCS6515 — 28 Pin Package

```
         Vss ─┤ 1      28 ├─ RES
         RDY ─┤ 2      27 ├─ Ø2
          Ø1 ─┤ 3      26 ├─ R/W
         IRQ ─┤ 4      25 ├─ DB0
         Vcc ─┤ 5      24 ├─ DB1
         AB0 ─┤ 6      23 ├─ DB2
         AB1 ─┤ 7      22 ├─ DB3
         AB2 ─┤ 8      21 ├─ DB4
         AB3 ─┤ 9      20 ├─ DB5
         AB4 ─┤ 10     19 ├─ DB6
         AB5 ─┤ 11     18 ├─ DB7
         AB6 ─┤ 12     17 ├─ AB11
         AB7 ─┤ 13     16 ├─ AB10
         AB8 ─┤ 14     15 ├─ AB9
```

MCS6515

Features of MCS6515

* 4K Addressable Bytes of Memory (AB00-AB11)
* Two phase clock input
* $\overline{IRQ}$ Interrupt
* 8 Bit Bi-Directional Data Bus
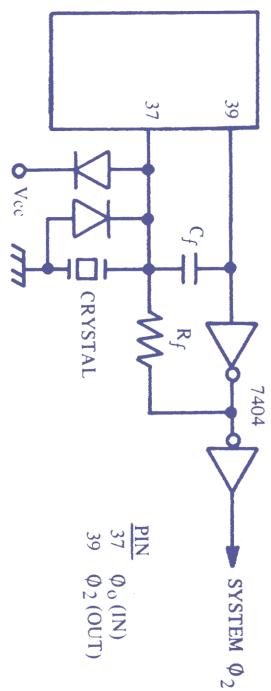
MCS6502

MCS6502 Parallel Mode Crystal Controlled Oscillator

V_{CC} · CRYSTAL · C_f · R_f · 7404 · SYSTEM Φ_2

PIN	
37	Φ_0 (IN)
39	Φ_2 (OUT)
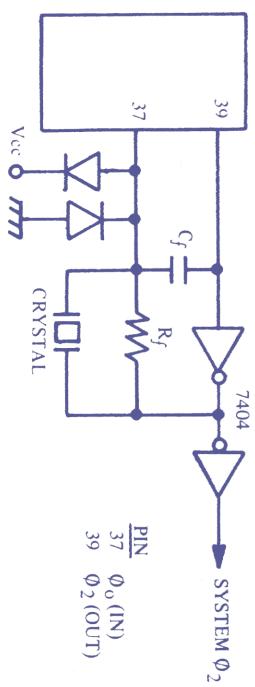
MCS6502 Series Mode Crystal Controlled Oscillator

V_{CC} · CRYSTAL · C_f · R_f · 7404 · SYSTEM Φ_2

PIN	
37	Φ_0 (IN)
39	Φ_2 (OUT)

MCS6502 Time Base Generator — RC Network

C_f · R_f · 7404 · SYSTEM Φ_2

PIN	
37	Φ_0 (IN)
39	Φ_2 (OUT)

MCS6503, MCS6504, MCS6505, MCS6506
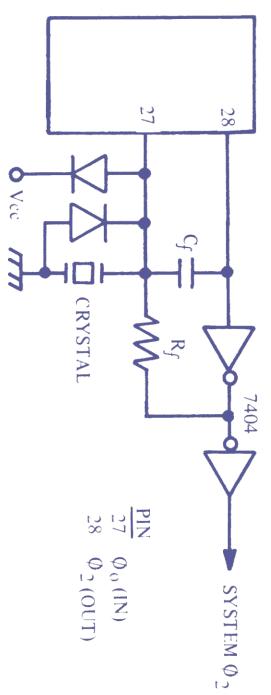
MCS6503,4,5,6 Parallel Mode Crystal Controlled Oscillator

V_{CC} · CRYSTAL · C_f · R_f · 7404 · SYSTEM Φ_2

PIN	
27	Φ_0 (IN)
28	Φ_2 (OUT)
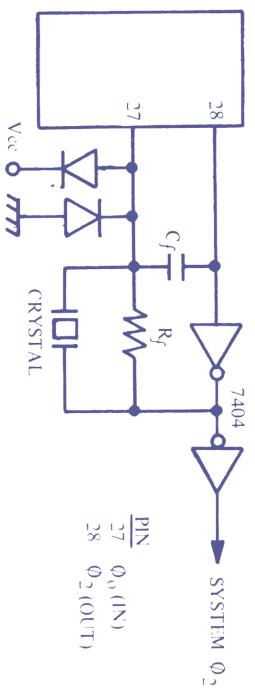
MCS6503,4,5,6 Series Mode Crystal Controlled Oscillator

V_{CC} · CRYSTAL · C_f · R_f · 7404 · SYSTEM Φ_2

PIN	
27	Φ_0 (IN)
28	Φ_2 (OUT)

MCS6503, MCS6504, MCS6505, MCS6506 Time Base Generation RC Network

C_f · R_f · 7404 · SYSTEM Φ_2

PIN	
27	Φ_0 (IN)
28	Φ_2 (OUT)

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